REVIEW ARTICLE

Radial Charge Fitting Curve for the Quantification and Classification of Parameters to Aid Diagnosis of Left Ventricular Hypertrophy

S. Rajalaxmi
Department of Biomedical Engineering, Mahendra College of Engineering,
Salem – Chennai Highways, NH-79, Minnampalli, Salem – 636106, India.

ABSTRACT: Left Ventricular Hypertrophy has a risk of increasing the brevity of the population if left untreated. Quantitative aid in the diagnosis and prognosis of Left Ventricular Hypertrophy to field experts is very essential to classify the disease for aiding prognosis. Endocardium segmentation of left and right ventricles is done through Local Chan-Vese (LCV) model using Radial Charge Fitting Curve. This is followed by the quantification of parameters left ventricular end-diastolic diameter, Intraventricular septum dimension and posterior wall thickness to evaluate left ventricle mass and relative wall thickness. This evaluation is useful in classifying the cardiac disease left ventricular hypertrophy as concentric hypertrophy, concentric remodeling, eccentric hypertrophy and no hypertrophy. The segmentation results are obtained with minimal iterations and parameters quantification has 98.76% accuracy with that of expert's report. The 2D echocardiography images for the research work were obtained from GE Vivid 7 Ultrasound machinery, Pranav Hospital, Salem.

KEYWORDS: Endocardium, Radial Charge Fitting Curve, Left Ventricular Hypertrophy, Left Ventricular End Diastolic Diameter, Intraventricular septum dimension, Posterior Wall Thickness, Relative Wall Thickness

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INTRODUCTION

The increase in the mass of Left Ventricular Hypertrophy (LVH) on the left ventricular endocardium is caused due to high workload in the heart. It is a chronic disease which may lead to atrial fibrillation, diastolic heart failure, systolic heart failure and sudden death in hypertensive patients [1]. Left ventricular hypertrophy has to be diagnosed effectively with echocardiograms for reducing morbidity. The assessment of cardiac function is done from echocardiography images for analyzing the parameters like wall thickness, shape, mass of the ventricles and atrium [2]. The disease is identified by increase in left ventricle mass, or increase in wall thickness. Left Ventricular Hypertrophy can be classified based on ventricular dilation and wall thickening. The geometrical patterns of left ventricle leads to the classification of: Left Ventricular Hypertrophy as Concentric Left Ventricular (LV) remodeling, Concentric LVH and Eccentric LVH [3-6]. The exact diagnosis of the disease helps in regressing the hypertension and thus reducing the severity of the disease.

LVH can be best diagnosed with proper segmentation of endocardium, which will help in the evaluation of parameters namely, left ventricle mass, posterior wall thickness and inter ventricular septum thickness. Hence segmentation of endocardium plays a major role in the quantification of above said parameters. Many segmentation techniques are available in the literature, among which active contour models and level set methods occupy a prevailing position [7-10]. Later Local Chan Vese Model proved to be more effective with the inclusion of global statistics in the level set function [11]. But all these techniques require initialization prior to segmentation with a contour. The segmentation results are sensitive to the location of the initial contour. This has computational complexity and avoids automation in segmentation. Hence to avoid this initialization problem, a new technique called Radial Fitting Curve based on Gauss law is proposed which generates the initial curve near

**Corresponding Author: hodbiomed@mahendracollege.com*
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the boundary [12]. After obtaining this contour, the segmentation of endocardium can be better tuned using Local Chan Vese Model.

Left Ventricular Hypertrophy can be classified based on ventricular dilation and wall thickening. Human heart comprises 4 chambers namely left ventricle, left atrium, right ventricle and right atrium. Each chamber must be efficient with geometry to hold and release blood on contraction. This geometry may reduce in size if the wall thickness increases which leads to a heart disease called Left Ventricular Hypertrophy. The geometrical patterns of left ventricle leads to the classification of Left Ventricular Hypertrophy as Concentric Left Ventricular (LV) Remodeling. Concentric LVH and Eccentric LVH [6]. The disease has to be classified efficiently with parameters including Left Ventricular End Diastolic Diameter (LVEDD), Posterior Wall Thickness (PWT), Intraventricular Septum Dimension (IVSD) and Relative Wall Thickness (RWT).

This review article is sculptured as LVH Parameters, Endocardium Segmentation & Parameters quantification, assessment of results, Parameter Quantification & Comparison with Expert's Report and Conclusion. The aim of the present study is to aid medical experts in quantifying the parameters of LVH by endocardium segmentation more precisely. The process comprises step by step procedure starting from filtering the speckle noised echocardiography images, followed by segmentation and classification.

1. *Left Ventricular Hypertrophy Parameters*

Left Ventricular Hypertrophy is characterized by enlarged endocardial mass or wall thickening. Geometric pattern of left ventricle can be defined based on relative wall thickness and left ventricle mass. Relative wall thickness is the ratio of diastolic Posterior Wall Thickness (PWT) to Left Ventricular End Diastolic Diameter (LVEDD). Left ventricle mass is the increase in the left ventricle cavity beyond its normal level. Left Ventricular mass is calculated according to the formula given by Devereux and Reichek [13] based on Penn Convention. The Penn convention includes endocardial boundaries of septum and posterior wall into the measurements of the LV internal diameter. LV mass is given by equation (1.1),

$$LV\ Mass = 1.04\ [(LVEDD + IVSD + PWT)^3 - (LVEDD)^3] - 13.6g \qquad (1.1)$$

Relative Wall Thickness (RWT) is given by equation (2),

$$RWT = \frac{2 * PWD}{LVEDD} \qquad (1.2)$$

where
LVEDD – Left Ventricular End Diastolic Diameter
IVSD – Intraventricular Septum Dimension
PWD – Posterior Wall Dimension
The reference values of LV mass, LVEDD, IVSD, PWD and RWT are shown in Table 1 [14]

Table 1: Attributes of Left Ventricle Geometry

Attributes	Female		Male	
	Normal Reference Range	Abnormal	Normal Reference Range	Abnormal
LVEDD (cm)	3.9 – 5.3	>5.3	4.2 – 5.9	>5.9
IVSD (cm)	0.6 - 0.9	>0.9	0.6 – 1.0	>1.0
PWD (cm)	0.6 - 0.9	>0.9	0.6 – 1.0	>1.0
LV Mass (gm)	67 – 162	>162	88 – 224	>224
RWT	0.22 – 0.42	>0.42	0.24 – 0.42	>0.42

The left ventricle geometric patterns classify Left Ventricular Hypertrophy as no LVH, Concentric LV Remodeling, Concentric LVH and Eccentric LVH. Concentric LV remodeling is

defined by normal mass and increased RWT. Concentric LVH is characterized by both increased mass and increased RWT. Eccentric LVH is described by increased mass and normal RWT. The reference range varies for male and female and is shown in Table 1.

Beyond the normal range, the values vary adversely and these abnormal cases are to be classified as concentric LVH, concentric LVR and eccentric LVH. This classification is shown in Figure 1. The attributes in Table 1 are measured from Apical 4 chamber view of echocardiography images and, LV mass and Relative wall thickness (RWT) is calculated based on equations (1.1) and (1.2) respectively. The values obtained are used to classify LVH.

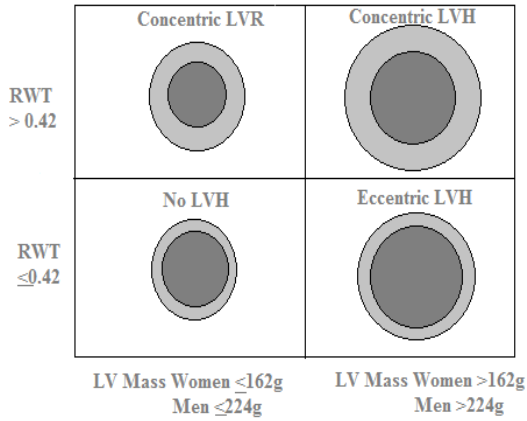


Figure 1: Classification of LVH

2. *Endocardium Segmentation & Parameters Quantification*

The measurement of the left ventricle geometric patterns plays a key role in classifying the disease more precisely [13]. These parameters have to be measured based on proper segmentation of endocardium. Here comes the significance of distinct segmentation of endocardium to have appropriate disease quantification. The accuracy of segmentation is most desired as the parameter quantification needed for Left Ventricular Hypertrophy and its classification is very critical. Hence segmentation using Local Chan Vese model with Radial Charge fitting curve will provide best results as per the requirement. The segmentation process followed by parameter measurement is preceded as shown in Figure 2 [12, 15, 16].

Step 1: Speckle Noise removal

Speckle noise is an innate noise present in ultrasound images. This speckle noise is a multiplicative noise which depends on pixel intensity. A straight kernel filter based on entropy is used to eliminate the speckle noise. The filter uses entropy parameter to measure the random occurrence of noise pixels in each row and column and to increase the image visibility. Straight kernels with 3 pixels each are chosen for the filtering process, and the filter is slided over the image to eliminate speckle. The filter measures the signal content from the noise in each straight kernel and replaces the pixels with noise-free intensity [15, 16].

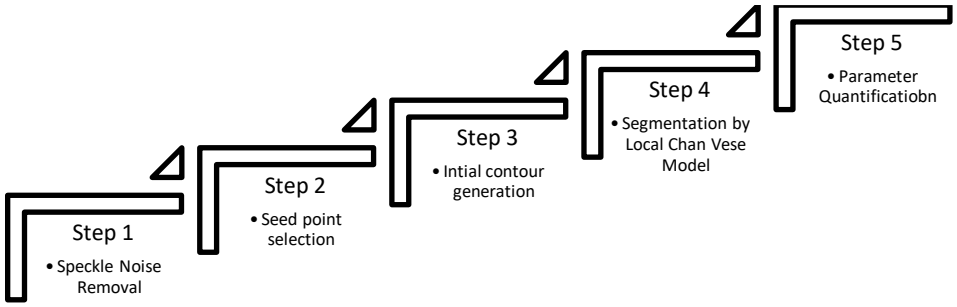


Figure 2: Steps for Endocardium Segmentation & Parameter Quantification

The proposed filter checks the unsystematic noise occurrence in the image and eliminates the noise by shifting in a linear fashion. The filter uses a standard straight kernel which considers the variance, mean, and entropy in a constrained scope. Entropy is a statistical measure of randomness that can be used to characterize the texture of the input image. The entropy parameter utilized in the filter aids in improving the image visibility, which is always poor in ultrasound images due to improper reception of echoes. Each pixel is assumed to be the centre of the neighbour pixels, and that pixel is replaced by performing a linear summation with a probability check of noise in each row and column. It is estimated that always a pixel

affected by noise will be predicted as a maximum intensity pixel or a minimum intensity pixel. The probability check of maximum or minimum intensity pixel is utilized for entropy calculation. The concept of entropy is utilized to enhance the luminance of each pixel. A process of linear regression combined with a measure of randomness of noise episode is performed to modify each pixel. The proposed filter is implemented with following equations (2.1, 2.2) [16].

$$J(i,j) = \frac{1}{e^{\log \sigma_k^2} + H_{\max}} [\sum_{j=j-1, j\neq j}^{j+1} J(i,j)] \quad (2.1)$$

$$J(i,j) = \frac{1}{e^{\log \sigma_k^2} + H_{\min}} [\sum_{j=j-1, j\neq j}^{j+1} J(i,j)] \quad (2.2)$$

where, J(i, j) – current pixel of the chosen kernel

σ_k^2- variance of the kernel

$$H_{\max} = -\frac{1}{\sigma}(P_{\max} \times \log_2 P_{\max}) \quad (2.3)$$

$$H_{\min} = -\frac{1}{\sigma}(P_{\min} \times \log_2 P_{\min}) \quad (2.4)$$

Equations (2.3) & (2.4) are the modified Shannon Entropy equation corresponding to maximum intensity pixel and minimum intensity pixel respectively.

Step 2: Seed point selection

A random selection of location is needed inside the endocardium to generate an initial contour. The advantage of the method is that random selection of seed point will promote a contour based on Gauss law and this eliminates the requisite of identifying the exact centre inside the chamber. The field experts are independent to choose a point from which the Radial fitting curve starts. The procedure after seed point selection is automatic which is followed by initial contour generation and segmentation using Local Chan Vese Model [12].

Step 3: Initial contour generation

An Endo fitting curve called Radial charge fitting curve is used for generation of initial contour within the endocardium. The curve is based on Gauss law and by which the endocardium is hypothesized to be an electrostatic conductor. From the seed point, the curve is generated with a radial sweeping in 4 cycles. According to Gauss law, an electrostatic conductor is charge free and hence the endocardium is presumed to have nil pixel intensity. This charge search will end after nearing the boundary [12].

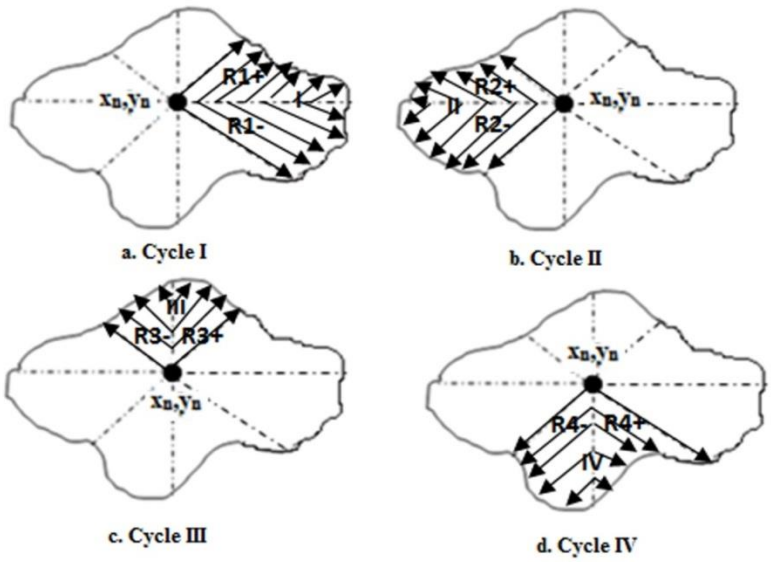


Figure 3: Four Cycles of Radial Charge Fitting Curve Method

In this radial approach, any initial seed point is selected within the Gaussian surface and searching of charge is done in a radial manner. In the previous method, when the charge is explored in a straight way, there are possibilities for neglecting the charges in the curved surfaces. The charge exploration entirely depends on the seed point selection. If the seed point selection is not the centroid of the Gaussian surface, the traversing along the width (w) may be quick in comparison with the traversing along the height (h). This may eliminate some of the charges on the surface which may lead to incomplete contour generation (Gaussian Surface). The Radial Charge Fitting Curve can be devised as a sweeping up of the chamber into 4 cycles. A Radial Sweeping method enhances a complete contour generation within the endocardium surface. The algorithmic steps for Radial Charge Fitting curve is shown below [12].

Algorithm

1. Start from any seed point (x_n, y_n)
2. Move along the radial path by finding the Electric Field Intensity (E)
3. Check the value of Electric Field Intensity (E). If E ≠ E_q (Quantified Electric Field Intensity), move to next point for charge exploration
4. Continue the same until the charge point (q) is attained
5. Return to the selected seed point (x_n, y_n)
6. Move to the next point along the width (w)
7. Repeat steps (2) to (6)
8. Repeat steps (2) to (7) until the charge point is attained along the width (w)

The algorithm explains the contour generation for a quarter cycle of the boundary to be segmented [12]. This method generates a complete closed contour with greater execution time than the Straight charge fitting curve. The cycles are illustrated in Figure 3

Cycle I

$$E_{R1+} = \frac{q_{(x-r,y+r+n)}}{d^2_{1(x-r,y+r+n)\to(x-r-1,y+r+n+1)}} \quad (2.5)$$

$$d_1 = \sqrt{\left|\left((x-r)-(x-r-1)\right)^2 + \left((y+r+n)-(y+r+n+1)\right)^2\right|} \quad (2.6)$$

$$E_{R1-} = \frac{q_{(x+r,y+r+n)}}{d^2_{2(x+r,y+r+n)\to(x+r+1,y+r+n+1)}} \quad (2.7)$$

$$d_2 = \sqrt{\left|\left((x+r)-(x+r+1)\right)^2 + \left((y+r+n)-(y+r+n+1)\right)^2\right|} \quad (2.8)$$

where $n = 0, \forall r \le q_p, (0 \le r \le q_p)$

$$n = 1, \forall r \le q_p, (0 \le r \le q_p) \dots\dots\dots \forall n \le q_p$$

Cycle II

$$E_{R2+} = \frac{q_{(x+r,y-r-n)}}{d^2_{3(x+r,y-r-n)\to(x+r+1,y-r-n-1)}} \quad (2.9)$$

$$d_3 = \sqrt{\left|\left((x+r)-(x+r+1)\right)^2 + \left((y-r-n)-(y-r-n-1)\right)^2\right|} \quad (2.10)$$

$$E_{R2-} = \frac{q_{(x-r,y-r-n)}}{d^2_{4(x-r,y-r-n)\to(x-r-1,y-r-n-1)}} \quad (2.11)$$

$$d_4 = \sqrt{\left|\left((x-r)-(x-r-1)\right)^2 + \left((y-r-n)-(y-r-n-1)\right)^2\right|} \quad (2.12)$$

where $n = 0, \forall r \le q_p, (0 \le r \le q_p)$

$$n = 1, \forall r \le q_p, (0 \le r \le q_p) \dots\dots\dots \forall n \le q_p$$

The above equations (2.5- 2.12) represent the calculation needed for traversing in the path of Cycle I and Cycle II. R1+ and R2+ represent the upper plane and R1- and R2- indicate the lower plane in the cycles as shown in figure 3 (a, b). The Euclidean distances are represented by d_1 and d_2 for Cycle I, and d_3 and d_4 for Cycle II. The value r represents the radial steps taken towards charge exploration q_p. Each path is traced in a radial manner for a fixed value of n until the conquer of the charge point q_p.

Cycle III

$$E_{R3+} = \frac{q_{(x-r1-n,y+r2)}}{d^2_{5(x-r1-n,y+r2)\rightarrow(x-r1-n-1,y+r2+1)}} \quad (2.13)$$

$$d_5 = \sqrt{\left|\left((x-r1-n)-(x-r1-n-1)\right)^2 + \left((y+r2)-(y+r2+1)\right)^2\right|} \quad (2.14)$$

$$E_{R3-} = \frac{q_{(x-r1-n,y-r2)}}{d^2_{6(x-r1-n,y-r2)\rightarrow(x-r1-n-1,y-r2-1)}} \quad (2.15)$$

$$d_6 = \sqrt{\left|\left((x-r1-n)-(x-r1-n-1)\right)^2 + \left((y-r2)-(y-r2-1)\right)^2\right|} \quad (2.16)$$

Cycle IV

$$E_{R4+} = \frac{q_{(x+r1+n,y+r2)}}{d^2_{7(x+r1+n,y+r2)\rightarrow(x+r1+n+1,y+r2+1)}} \quad (2.17)$$

$$d_7 = \sqrt{\left|\left((x+r1+n)-(x+r1+n+1)\right)^2 + \left((y+r2)-(y+r2+1)\right)^2\right|} \quad (2.18)$$

$$E_{R4-} = \frac{q_{(x+r1+n,y-r2)}}{d^2_{8(x+r1+n,y-r2)\rightarrow(x+r1+n+1,y-r2-1)}}$$

$$d_8 = \sqrt{\left|\left((x+r1+n)-(x+r1+n+1)\right)^2 + \left((y-r2)-(y-r2-1)\right)^2\right|} \quad (2.19)$$

where $n = 0, \forall r1 \le q_p, (0 \le r1 \le q_p)$

$$r2 = r1 - 1$$

$$n = 1, \forall r1 \le q_p, (0 \le r1 \le q_p) \dots\dots\dots \forall n \le q_p$$

The above equations (2.13- 2.19) represent the calculation needed for traversing in the path of Cycle III and Cycle IV. R3+ and R4+ represent the right side plane and R3- and R4- indicate the left side plane in the cycles as shown in figure 3 (c) and 4 (d). The Euclidean distances are represented by d_5 and d_6 for Cycle III, and d_7 and d_8 for Cycle IV. The values r1 and r2 represents the radial steps taken towards charge exploration q_p. Each path is traced in a radial manner for a fixed value of n until the conquer of the charge point q_p.

Step 4: Endocardium Segmentation using Local Chan Vese Model

Local Chan Vese Model (LCV) is well known for segmentation of intensity inhomogeneity images. The model is based on techniques of curve evolution, local statistical function and level set methods [11]. The energy function of LCV model comprises 3 parts namely the global term E^G, local term E^L and regularization term E^R. The energy function of LCV is shown in equation (2.20)

$$E^{LCV} = \alpha E^G + \beta E^L + E^R \quad (2.20)$$

This model is a segmentation technique based on the techniques of curve evolution, local statistical function and level set method. The energy functional is based on three terms namely global term, local term and regularization term.

The Global term is included to represent the global information which is given by Equation (2.21)

$$E^G(c_1, c_2, \Phi) = \int |u_0(x,y) - c_1|^2 H\big(\Phi(x,y)\big)dxdy + \int |u_0(x,y) - c_2|^2 \Big(1 - H\big(\Phi(x,y)\big)\Big)dxdy \quad (2.21)$$

As the medical images suffer from intensity in homogeneity problem, local statistical characteristics are considered in the local term. The local term is given by Equation (2.22)

$$E^L(d_1, d_2, C) = \int_{insideC} |g_k * u_0(x,y) - u_0(x,y) - d_1|^2 \, dxdy + \int_{outsideC} |g_k * u_0(x,y) - u_0(x,y) - d_2|^2 \, dxdy \quad (2.22)$$

To regularize the length of the evolving curve and to control the penalty on the curve, the regularization term is included. It is given by Equation (2.23)

$$E^R(\Phi) = \mu \int \delta(\Phi(x,y))|\nabla\Phi(x,y)| \, dxdy + \int \tfrac{1}{2}(|\nabla\Phi(x,y)| - 1)^2 dxdy \text{ --- } (2.23)$$

The global term is based on global information. To represent the intensity inhomogeneity effect, local term is incorporated with local statistical information. To improvise the segmentation and to avoid isolated regions, regularization term is included. The parameters α and β represent positive values and are used to maintain a tradeoff between global term and local term. The parameters α and β are set as 1 for intensity inhomogeneity images [11].

In LCV model the termination criterion for curve evolution is based on local term and global term. As the terms minimize and reach zero, the curve evolves to the true boundaries. For each iteration, the length of the evolving curve L(c(t)), is compared with ξ_{length} which becomes greater than the length of the evolving curve.

This is done for fixed number of iterations T_{it} = 10 and ξ_{length}= 5. The condition for curve evolution is given by equation (2.24)

$$[L\,c(t) - L\,c(t\text{-}1)] \leq \xi_{length} \qquad (2.24)$$

In the proposed work of endocardium segmentation as the initial contour generated by radial charge fitting curve is close to the boundary, T_{it} is reduced to 2 and ξ_{length}= 5. The number of iterations is reduced than with direct application of Local Chan Vese Model. The implementation of the method is given in the flowchart given in Figure 4

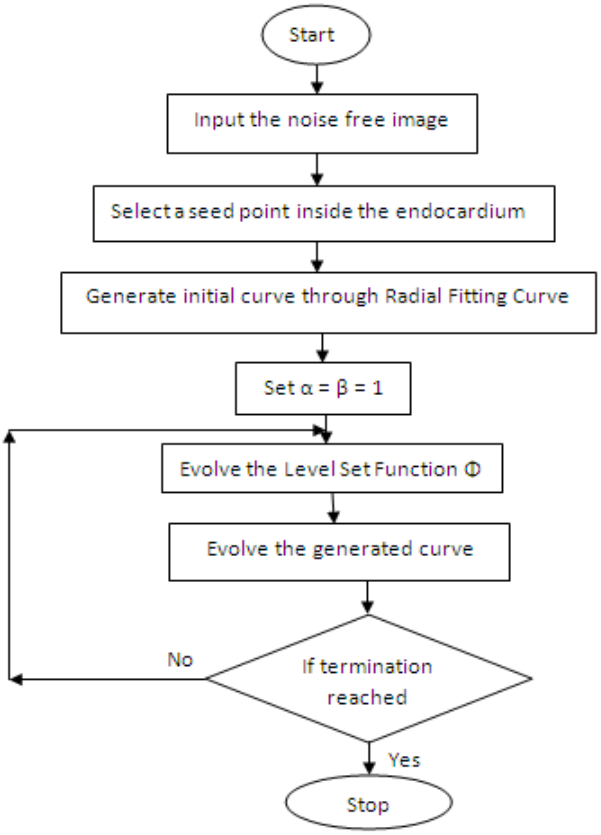


Figure 4: Flowchart of Local Chan Vese Model using Radial Charge Fitting Curve

The noise free image obtained by the entropy based Straight kernel filter [16] is given as the input. The filter removes speckle noise which is the dominant noise in echocardiography images. The Local Chan Vese Model is applied after the generation of initial contour through Radial Charge Fitting Curve. The parameters α and β are set as 1 and the results are obtained. The level set function is evolved using the specified equations and the termination criterion is checked after each evolution. If the contour has reached the endocardium boundary, the curve evolution is stopped and hence the endocardium chamber is segmented in minimal iterations [17, 18].

Step 5: Measurement of parameters LVEDD, PWD and IVSD

Left ventricular hypertrophy is a chronic cardiac disease characterized by increase in Left Ventricle Mass (LVM) and / or increase in Relative Wall Thickness (RWT). The equations (1.1) and (1.2) can be used for calculating LVM and RWT. Apical 4 chamber view of echocardiography image is used for measuring the parameters LVEDD, PWD and IVSD in the proposed work. A sample measurement of the said parameters is shown in Figure 5. LVEDD is the parameter measured inside the left ventricle, IVSd is measured between left and right ventricles and PWT is measured outside the left ventricle.

Figure 5: Apical 4 Chamber View with parameters (20 iterations)

3. RESULTS & DISCUSSION

A total of 153 gray scale sequences of Apical 4 chamber view including both male and female with cases having Concentric LVH, Concentric LVR, Eccentric LVH and no LVH are collected from Pranav Hospital, Salem, Tamilnadu. The expert's disease diagnosis statement is obtained for all the images. The images are obtained for research with the consent of patients. The images are collected from GE Vivid 7 Ultrasound machinery. The simulation of these Echo cardiographic images is performed in Matlab R2012, on a personal computer with Intel Core 2 Duo processor, 2.93 GHz, 2 GB Random Access Memory (RAM). All the Echo cardiography images have undergone the process of noise removal, seed selection, initial contour generation using Radial Charge Fitting curve, endocardium segmentation using Local Chan Vese Model and parameter quantification. The segmentation results through Local Chan Vese Model with Radial Charge Fitting curve has produced the results with little iteration and thus reducing the computational complexity. Out of those 4 cases the results of – one female with Concentric LVH, one male with Concentric LVR, one female with Eccentric LVH and one male with no LVH are shown respectively in Figures 6, 7, 8, 9. The measurements given by medical experts are shown for comparison. The parameter quantification through the proposed endocardium segmentation has 98.76% accuracy.

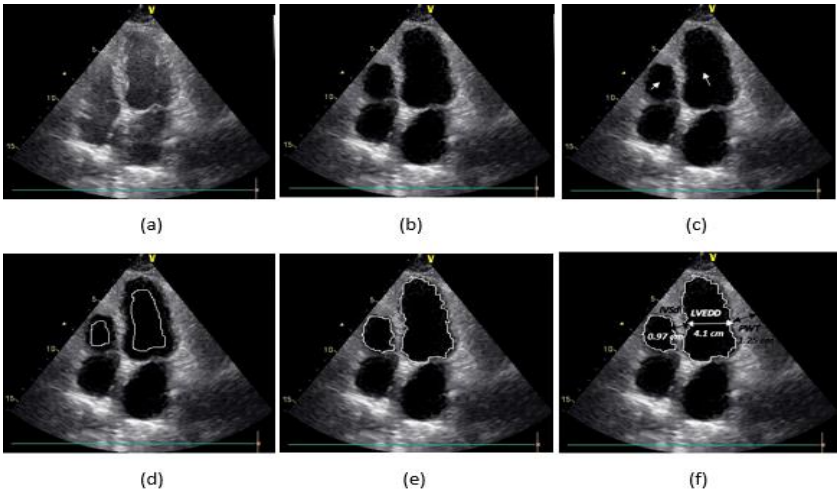


Figure 6: Apical 4 Chamber view of Concentric LVH (end diastole)
(a) Noisy image (b) Noise filtered image with Entropy filter (c) Seed selection (d) Initial contour using Radial charge fitting curve (e) Segmentation using Local Chan Vese Model (19 iterations) (f) Parameter Quantification

The image shown in Figure 6 is the Apical 4 Chamber view of Rohini, aged 56. The patient has Concentric LVH for a period of 3 years. Figure 6 (a) is the original image with noise, and 6 (b) is the image after the application of Entropy based straight kernel filter. The noisy pixels are eliminated from the endocardium using the filter for better visualization of the chambers. A random seed selection done in both the left and right ventricles is shown in 6 (c). The results after initial contour generation and segmented image using Local Chan Vese Model is shown in Figure 6 (d) and 6 (e). Accurate segmentation results are obtained with 19 iterations. The image in Figure 6 (f) shows the parameters measured after segmentation. Concentric LVH is characterized by both increased LV mass and RWT. The measurements are done at the end of diastole. The measurements are obtained in terms of number of pixels and they are converted to equivalent centimetre.

Case 2: Concentric LV Remodeling

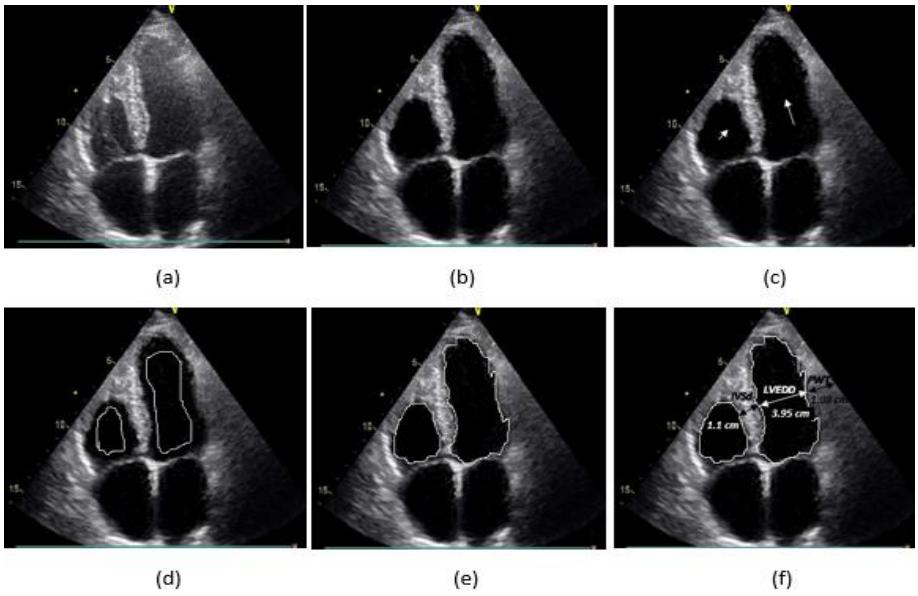


Figure 7: Apical 4 Chamber view of Concentric LVR (end diastole)
(a) Noisy image (b) Noise filtered image with Entropy filter (c) Seed selection (d) Initial contour using Radial charge fitting curve (e) Segmentation using Local Chan Vese Model (22 iterations) (f) Parameter Quantification

The image shown in Figure 7 is the Apical 4 Chamber view of Govin, aged 62. The patient has Concentric LVR for a period of 6 years. Figure 7 (a) is the original image with noise and 7 (b) is the image after the application of Entropy based straight kernel filter. The noisy pixels are eliminated from the endocardium using the filter for better visualization of the chambers. A random seed selection done in both the left and right ventricles is shown in 7 (c). The results after initial contour generation and segmented image using Local Chan Vese Model are shown in figure 7 (d) and 7 (e). The endocardium segmentation is obtained with 22 iterations. The image in 7 (f) shows the parameters measured after segmentation. Concentric LV Remodeling is characterized by normal LV mass and increased RWT.

Case 3: Eccentric LVH

The image shown in Figure 8 is the Apical 4 Chamber view of Lalitha, aged 43. The patient has Eccentric LVH for a period of 2 years. Figure 7 (a) is the original image with noise and 8 (b) is the image after the application of Entropy based straight kernel filter. The noisy pixels are eliminated from the endocardium using the filter for better visualization of the chambers. A random seed selection done in both the left and right ventricles is shown in 7 (c). The results after initial contour generation and segmented image using Local Chan Vese Model are shown in figure 8 (d) and 8 (e). The segmentation is attained with 18 iterations. The image in 8 (f) shows the parameters measured after segmentation. Eccentric LVH is characterized by increased LV mass and normal RWT.

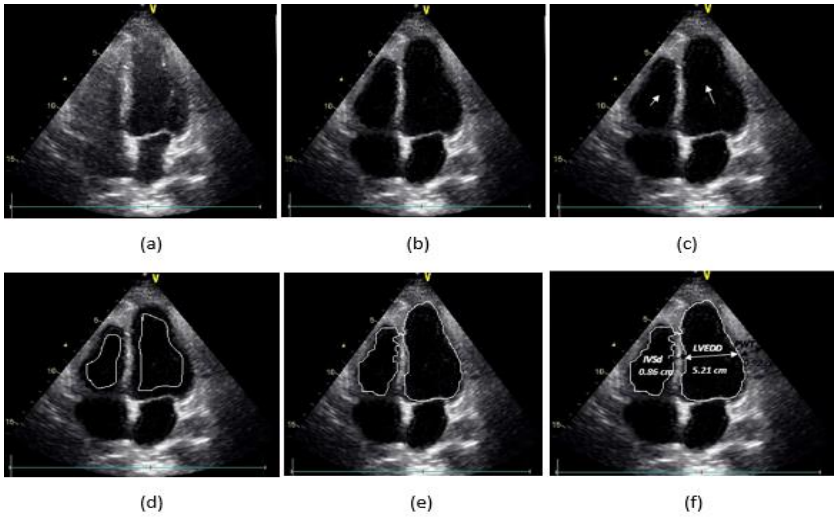


Figure 8: Apical 4 Chamber view of Eccentric LVH (end diastole)
(a) Noisy image (b) Noise filtered image with Entropy filter (c) Seed selection (d) Initial contour using Radial charge fitting curve (e) Segmentation using Local Chan Vese Model (18 iterations) (f) Parameter Quantification

Case 4: No LVH (Normal)

The image shown in Figure 9 is the Apical 4 Chamber view of Ram, aged 35. The volunteer has normal LV geometry. The volunteer has consented to have the echo test for research purpose. Figure 9 (a) is the original image with noise and 9 (b) is the image after the application of Entropy based straight kernel filter. The noisy pixels are eliminated from the endocardium using the filter for better visualization of the chambers. A random seed selection done in both the left and right ventricles is shown in 9 (c). The results after initial contour generation and segmented images using Local Chan Vese Model are shown in Figure 9 (d) & 9 (e). The ventricles are segmented in 20 iterations. The image in Figure 9 (f) shows the parameters measured after segmentation. The normal heart is characterized by normal LV mass and normal RWT. In the case of normal heart, the geometry of left ventricle is characterized by normal values shown in Table 1. It can be visualized from Figure 9 that all the chambers of the heart are normal sized and not enlarged.

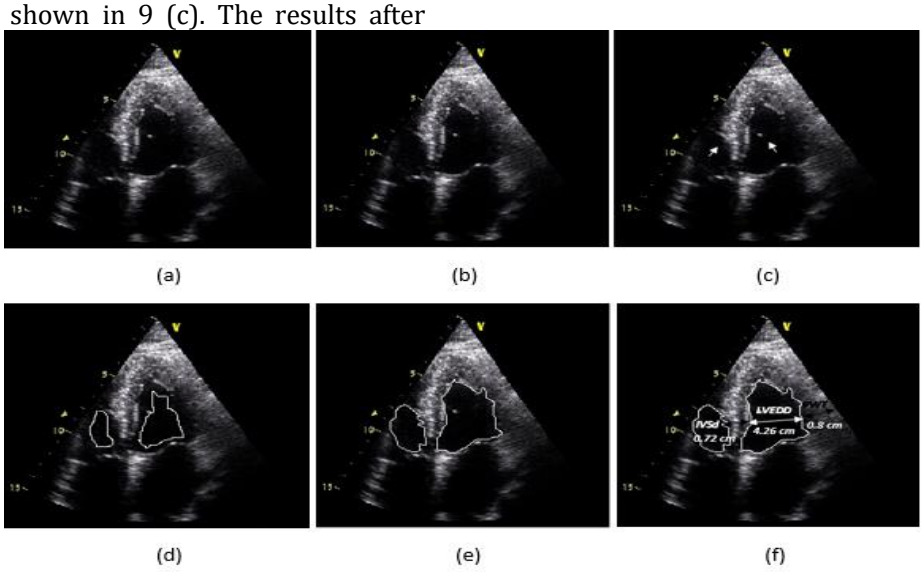
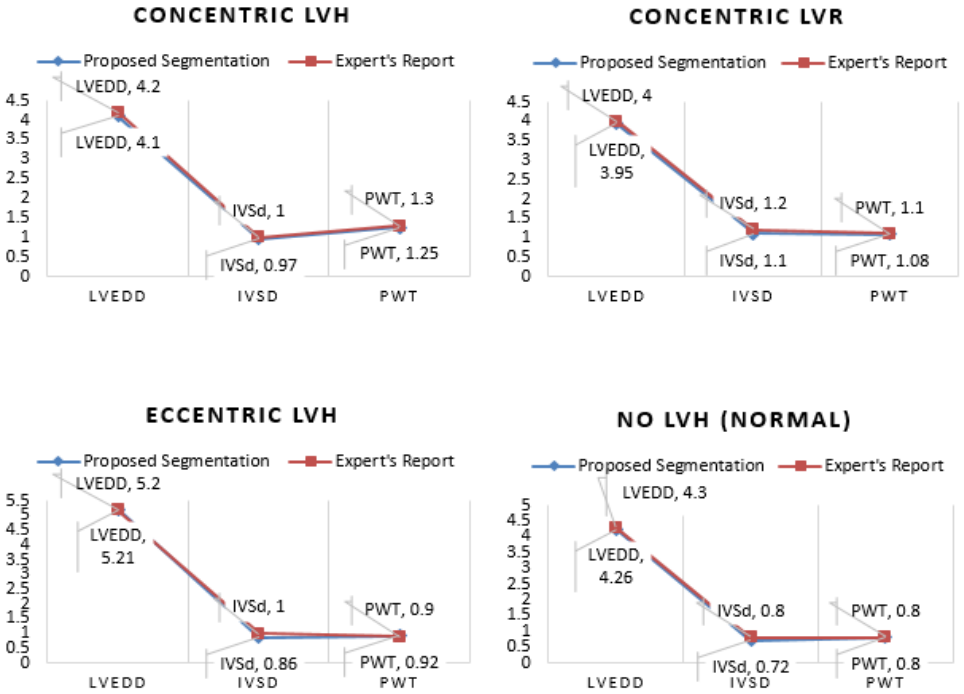


Figure 9: Apical 4 Chamber view of No LVH / Normal (end diastole)
(a) Noisy image (b) Noise filtered image with Entropy filter (c) Seed selection (d) Initial contour using Radial charge fitting curve (e) Segmentation using Local Chan Vese Model (20 iterations) (f) Parameter Quantification

5. Parameter Quantification & Comparison with Expert's Report

Sample calculation of LV mass and Relative Wall thickness from the acquired parameters is shown in Table 2. The measurements are obtained in pixel notations in Matlab and are converted into equivalent centimeter. The Left ventricle mass is calculated by using the Penn convention formula shown in equation (2.1). Relative Wall thickness is the ratio of Posterior Wall thickness and Left Ventricular end diastolic dimension. From Table 2, the values obtained by endocardium segmentation and that collected from medical expert are very close. The LV mass for case 1 is 177.25 gm by the proposed segmentation and that by expert's report is 180.16 gm. The normal range of LV mass for female is 162 gm and RWT is 0.42. From Table 2, it is evident that both LV mass and RWT are greater than the normal range. Hence the disease is classified as Concentric LVH. The diagnosis is similar in the case of proposed work and by expert.



(b) Figure 10: Comparison between Expert's report & proposed segmentation

In case 2, for Concentric LV Remodeling, LV mass is normal but RWT is greater than the normal level. The Relative Wall thickness is same for both the proposed work and expert's report. The LV mass differs by ± 4 gm. Eccentric Hypertrophy is a special case in which RWT is normal but LV mass is greater than 162 gm for female and 224 gm for male. In the case considered, the LV mass obtained is 194.51 gm and 198.75 gm by proposed endocardium segmentation and expert's report respectively.

In case 4, the volunteer has normal cardiac geometry and all the values are within the specified range. The measurements LVEDD, IVSd and PWT obtained by the proposed endocardium segmentation and expert's report are very close and differ by ± 0.1 cm. The closeness between expert's report and the proposed parameter measurement is shown in Figure 10. All the 4 cases are shown for the parameters LVEDD, IVSd and RWT. The Y axis shows the values in centimeter and X axis shows the parameters.

CONCLUSION

Endocardium segmentation using Local Chan Vese Model with Radial Charge fitting curve is done to quantify the parameters needed for Left Ventricular Hypertrophy, a serious cardiac disease. The parameters namely LVEDD, IVSd and PWT are measured from 153 Apical 4 Chamber view gray scale images and are compared with that of expert's report. The results obtained through Local Chan Vese Model with Radial charge fitting curve has minimal computational complexity as the method has automatic contour generation very close to the endocardium boundary. Also the parameter measurements from the segmentation results

are very close to the expert's measurements and have produced 98.76% accuracy. The proposed work is to aid the medical experts with automation in endocardium segmentation and parameter quantification of Left Ventricular Hypertrophy.

Table 2: Parameter Quantification and Comparison with Expert's Report

Parameters	Values obtained from endocardium segmentation	Values obtained by expert	Disease Diagnosed from proposed work	Disease Diagnosed by expert
Case 1: Concentric LVH – Rohini aged 56				
LVEDD (cm)	4.1 cm	4.2 cm	Concentric LVH	Concentric LVH
IVSd (cm)	0.97 cm	1.0 cm		
PWT (cm)	1.25 cm	1.3 cm		
LV Mass (gm)	177.25 gm	180.16 gm		
RWT (cm)	0.60	0.62		
Case 2: Concentric LVR - Govin aged 62				
LVEDD (cm)	3.95	4.0	Concentric LVR	Concentric LVR
IVSd (cm)	1.1	1.2		
PWT (cm)	1.08	1.1		
LV Mass (gm)	161.87	164.36		
RWT (cm)	0.55	0.55		
Case 3: Eccentric LVH – Lalitha aged 43				
LVEDD (cm)	5.21	5.2	Eccentric LVH	Eccentric LVH
IVSd (cm)	0.86	1.0		
PWT (cm)	0.92	0.9		
LV Mass (gm)	194.51	198.75		
RWT (cm)	0.35	0.35		
Case 4: No LVH (Normal)- Ramkumar aged 35				
LVEDD (cm)	4.26	4.3	No LVH	No LVH
IVSd (cm)	0.72	0.8		
PWT (cm)	0.8	0.8		
LV Mass (gm)	106.82	110.37		
RWT (cm)	0.37	0.37		

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